NAVAL BIODYNAMICS LABORATORY
NBDL-91R002

DYNAMIC RESPONSE OF THE HYBRID III DUMMY TO $+G_Z$ SIMULATED SHIP SHOCK -- CUSHIONED VS HARD SEATS

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Research Report

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1. INTRODUCTION

Shock trials conducted by the Naval Sea Systems Command (NAVSEASYSCOM) represent continuing efforts toward improving ship performance and survivability in combat. The crew onboard a ship at-sea which is undergoing shock trials brace themselves for the upcoming shock by assuming a standard crouched position with bent knees. Since this defensive posture is not representative of a real-life situation, the question arose as to the possibility of deleterious effects of shock on crewmembers while seated at their duty stations performing normal tasks and unaware of any upcoming shock forces.

To obtain insight into the potential for shock forces which may injure unaware crewmembers, NAVSEASYSCOM tasked the Naval Biodynamics Laboratory (NAVBIODYNLAB) with measuring dynamic response to ship shock on an instrumented anthropomorphic manikin. The manikin was seated in a Special Purpose Operator's Chair (SPOC) which was located in the Combat Information Center (CIC) onboard the heavy cruiser, USS MOBILE BAY (CG-53). Subsequently, NAVBIODYNLAB also participated in the shock trials onboard a Nimitz class aircraft carrier, the USS ROOSEVELT (CVN-71). The manikin was deployed in a standing position during this operation.

Prior to transferring the equipment to the ships, the Laboratory conducted a series of in-house simulated shock tests in the vertical ($+G_z$) direction. The vertical accelerator was used as the experimental shock-imparting device and previous USS YORKTOWN (CG-48) cruiser shock trial data was used as the template. The purpose of these tests was to verify the ability of the instrumentation and data acquisition hardware to operate under severe shock conditions. The goal was successfully accomplished and demonstrated that the vertical accelerator is indeed capable of reproducing the vertical component of shock forces measured during actual shock trials (Figure 1). This capability suggested a variety of valuable experiments concerning human response to ship shock performed in a simulated environment. This report documents one such experiment.

This Command, since 1971, has performed related research in the area of human dynamic response to various impact stimuli and has developed instrumentation, data acquisition and data analysis techniques directly applicable to the subject task. NAVBIODYNLAB research has utilized instrumented manikins, human volunteers and non-human primates.

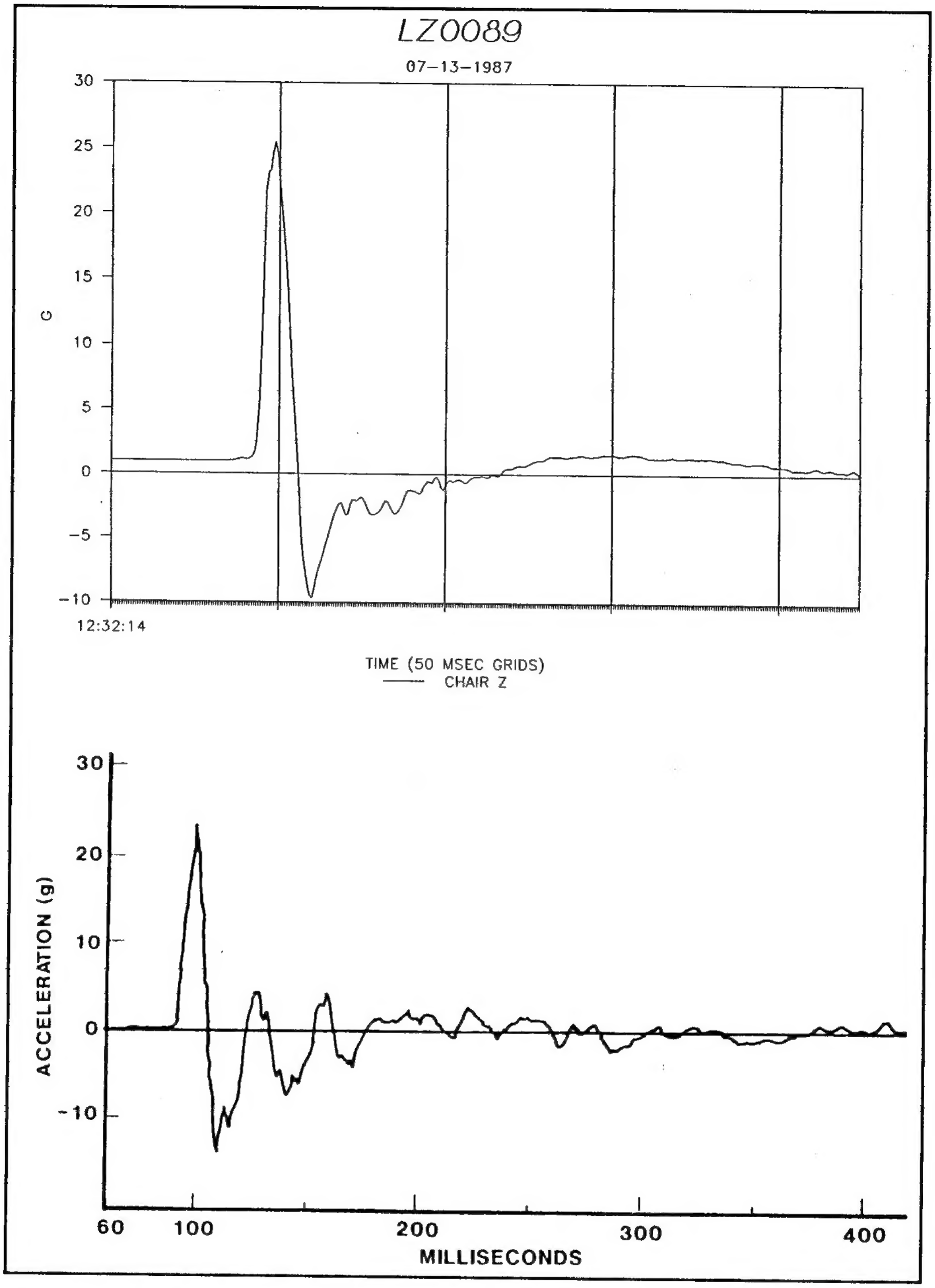


Figure 1. Comparisons of Shock Forces Measured on Vertical Accelerator (top) and USS YORKTOWN (CG-48).

2. METHODS

2.1 TEST ITEM

A fiftieth percentile Hybrid III manikin was selected for this project. The Hybrid III is the most advanced available test device in terms of biofidelity, and is representative of the weight and general body structure of a healthy male in the general population. This manikin is the Federal Government's standard test article for evaluating automotive restraint systems.

2.2 INSTRUMENTATION

The Hybrid III manikin's shock input and resultant dynamic response were measured using four accelerometer clusters. To provide greater clarity and understanding of the manikin response to the shock tests, it is necessary to describe the nomenclatures, placements and axes orientation of the transducers as mounted on the chair pedestal and in the manikin. Figure 2 depicts the manikin and indicates the transducer locations and alignments. Transducers labeled as X, Y, and Z were linear accelerometers, while those labeled AX, AY, and AZ were angular accelerometers. Packages containing three accelerometers each were installed in the head and first thoracic vertebrae (T-1) area, and aligned to the X, Y, and Z coordinate system shown in Figure 2. A package containing two accelerometers was installed in the pelvis and similarly aligned with the local coordinate system. Three angular accelerometers were also installed in the head and oriented such as to measure angular accelerations about the previously defined head coordinate system. This additional head instrumentation was deemed necessary, since substantial head rotation has been observed in prior human research involving inputs similar to those expected in the ship shock trials, and is thought to be a significant head injury parameter.

The specific transducer packages used for the experiments were:

- Chair X, Y, and Z: Endevco Model 2262-25 linear accelerometers.
- Pelvis X and Z: Endevco Model 2262-25 linear accelerometers.
- T-1 X, Y and Z: Entran Model EGA-50D linear accelerometers.
- Head X, Y, and Z: Entran Model EGA-50D linear accelerometers.
- Head AX, AY, and AZ: Endevco Model 7302B angular accelerometers.

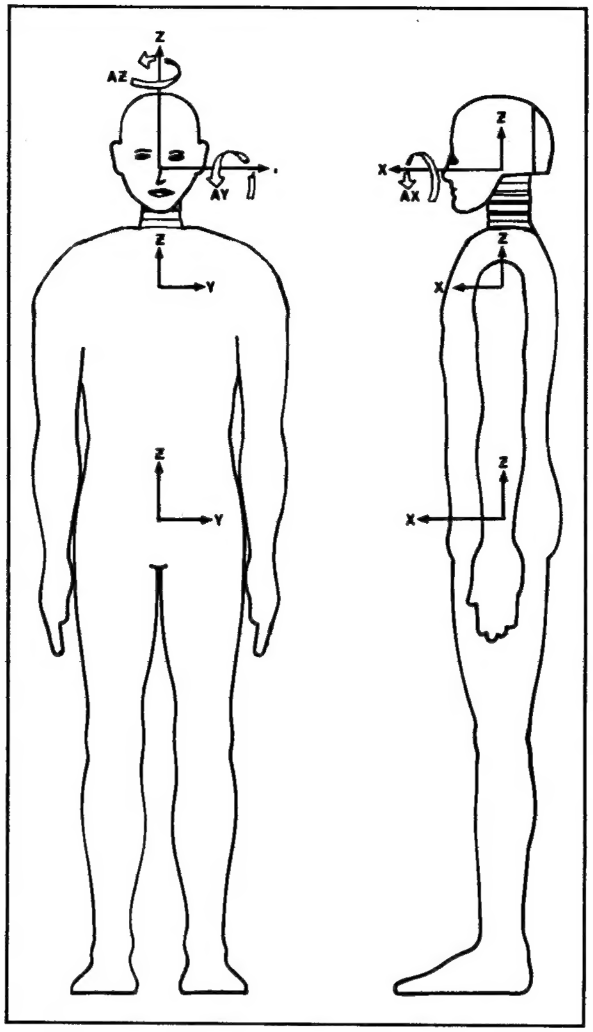


Figure 2. Coordinate System Definition.

2.3 TEST FIXTURE

The device used to impart the shock forces was NAVBIODYNLAB's Vertical Accelerator, a 6-inch diameter pneumatically powered linear accelerator capable of 40,000 pounds of thrust. It propels a carriage capable of carrying a payload in excess of 500 pounds upwards, along a 40-ft long tower-supported rail system.

2.4 SEATS

Figure 3 depicts the seat-manikin configuration utilizing the Special Purpose Operator's chair (SPOC) in the firing position on the Vertical Accelerator. The two hard-bottomed seats used in subject experiments are shown in Figures 4 and 5, respectively. The reason for using two hard seats will be discussed quantitatively in the RESULTS section. Qualitatively, the reason is as follows: the seat shown in Figure 4 (hard seat #1) consists of a steel-frame base,

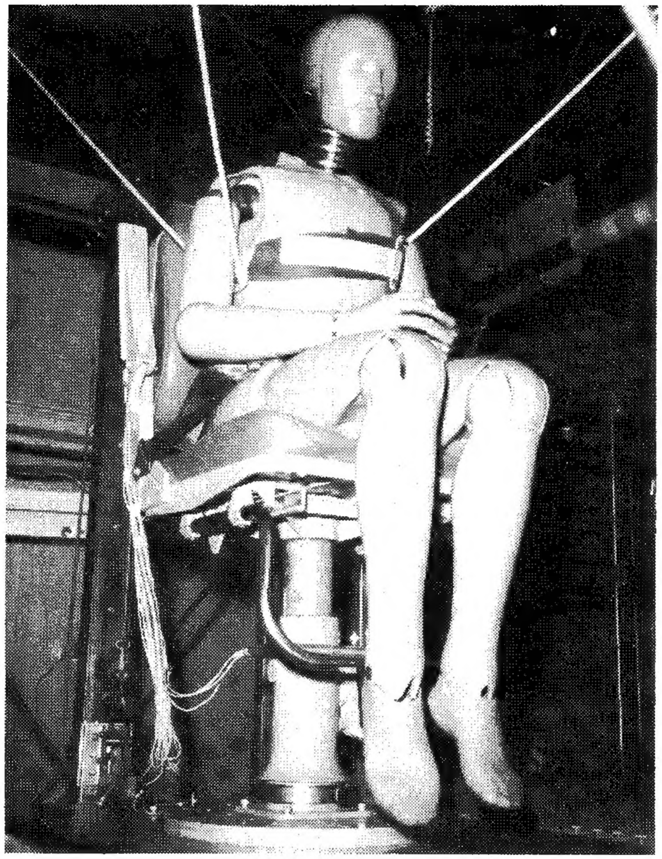


Figure 3. SPOC on Vertical Accelerator.

a wooden spacer sandwiched between two 0.75 inch aluminum plates, and a conformal molded fiberglass seat. This seat has been used at NAVBIODYNLAB for many years for a variety of experiments, including low level shock. It was speculated that the conformal "saddle" shape of the seat might introduce a significant forward motion to the manikin. This was confirmed by the initial experiments. The seat was modified to the configuration shown in Figure 5 (hard seat #2), in which the conformal fiberglass insert was replaced by a flat plate parallel to the accelerator carriage, and therefore, more likely to impart a purely vertical input to the manikin, similar to that of the SPOC.

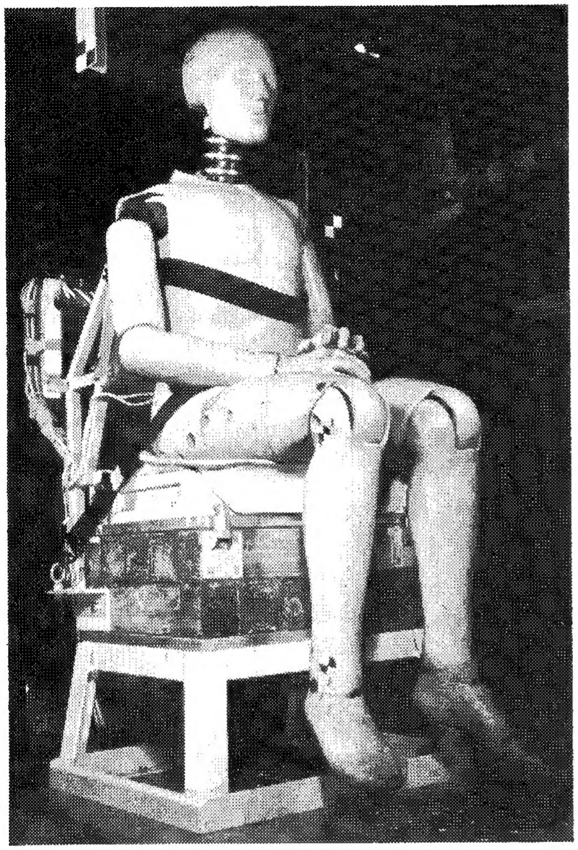


Figure 4. Hard Seat #1.

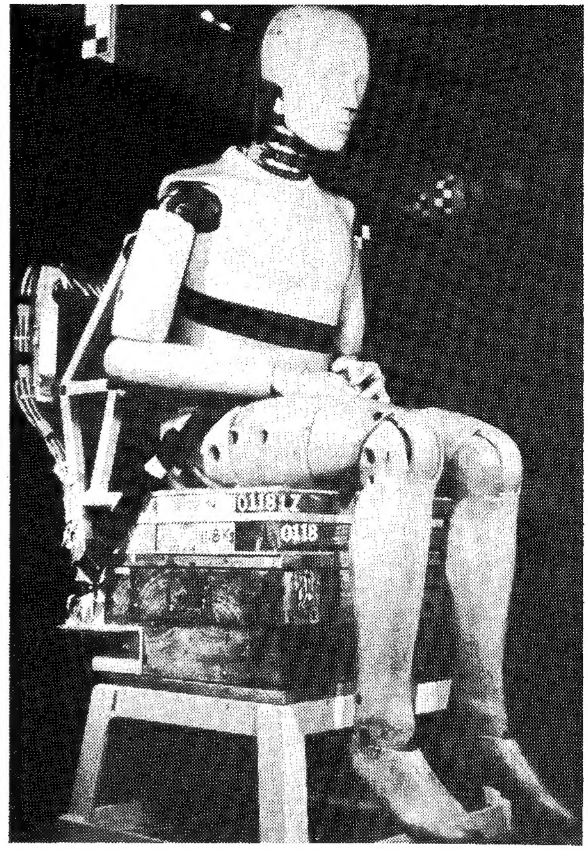


Figure 5. Hard Seat #2.

3. RESULTS

3.1 REPEATABILITY

To verify the ability of the Vertical Accelerator and the manikin-seat combinations to deliver reliable results, two tests at 10 Gs and two at 25 Gs were conducted. The shock propagation through the manikin was measured. The tests were conducted with the SPOC and hard seat #1. The results for the SPOC are shown in Figures 6 (10 Gs) and Figure 7 (25 Gs). It is obvious that repeatability is excellent at all measurement stations. Similar results were obtained for the hard seat configuration, as shown in Figure 8 (10 Gs) and Figure 9 (25 Gs). The only response with somewhat degraded repeatability is the pelvis at 10 Gs input. However, since this did not carry over to the 25 G condition, it can only be considered anomalous, inasmuch as all other responses exhibit good fidelity.

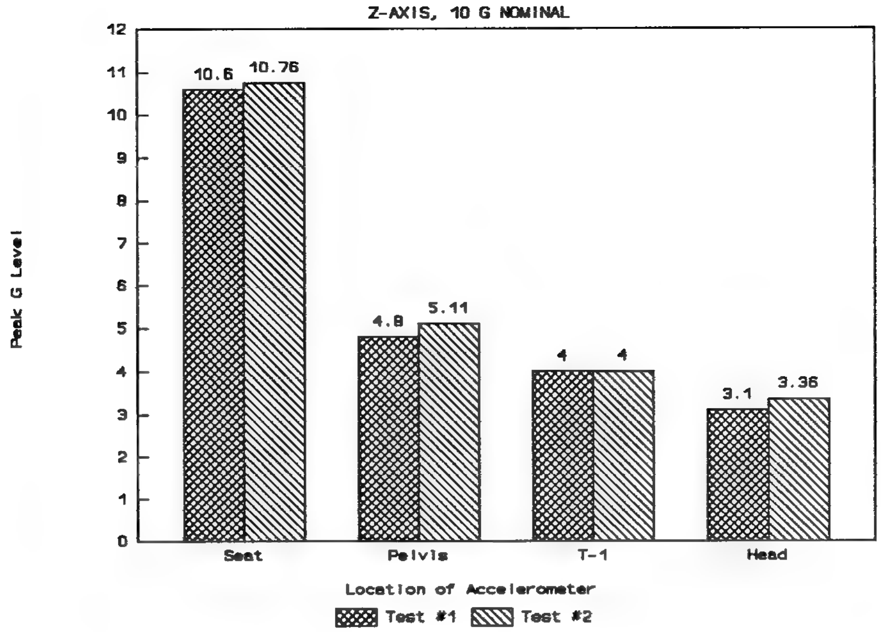


Figure 6. Soft Seat Repeatability.

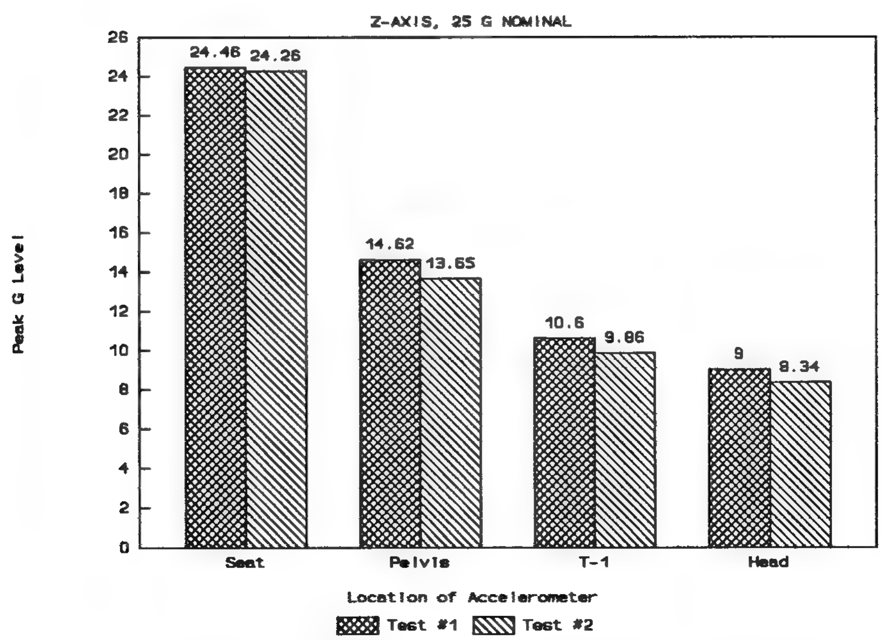


Figure 7. Soft Seat Repeatability.

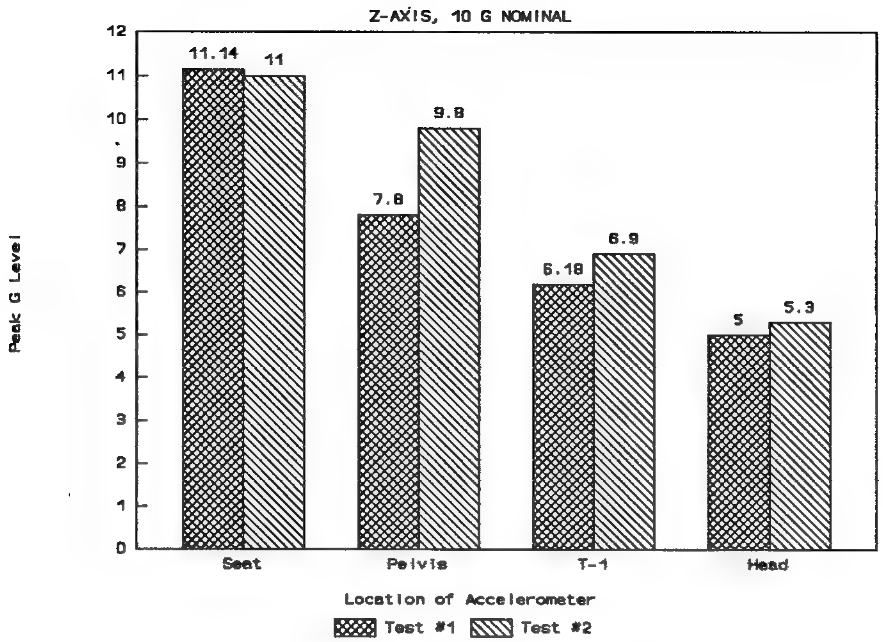


Figure 8. Hard Seat Repeatability.

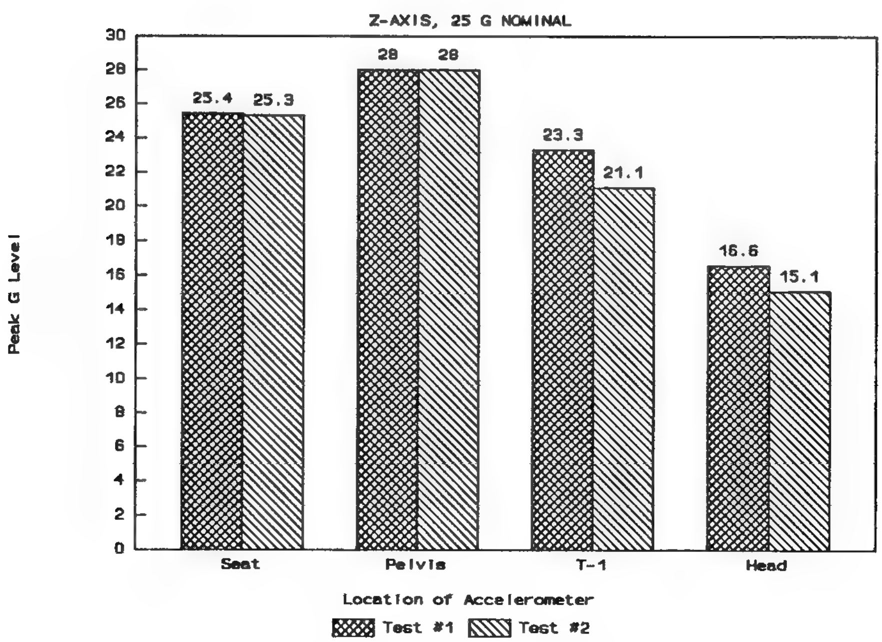


Figure 9. Hard Seat Repeatability.

3.2 HARD SEAT COMPARISON

Due to its shape, the comformal hard seat was suspected of introducing a significant X component of acceleration. Figures 10 and 11 show the X and Z components of acceleration at the pelvis for both hard seat configurations. It is evident that the difference in response is significant at the higher acceleration levels. It is obvious from the response of the modified seat that the X input component is greatly reduced. Not unexpectedly, since the X component was reduced by the redesign, the pelvis Z component of the modified seat is larger. The remaining comparison data presented are for the SPOC and hard seat #2 only.

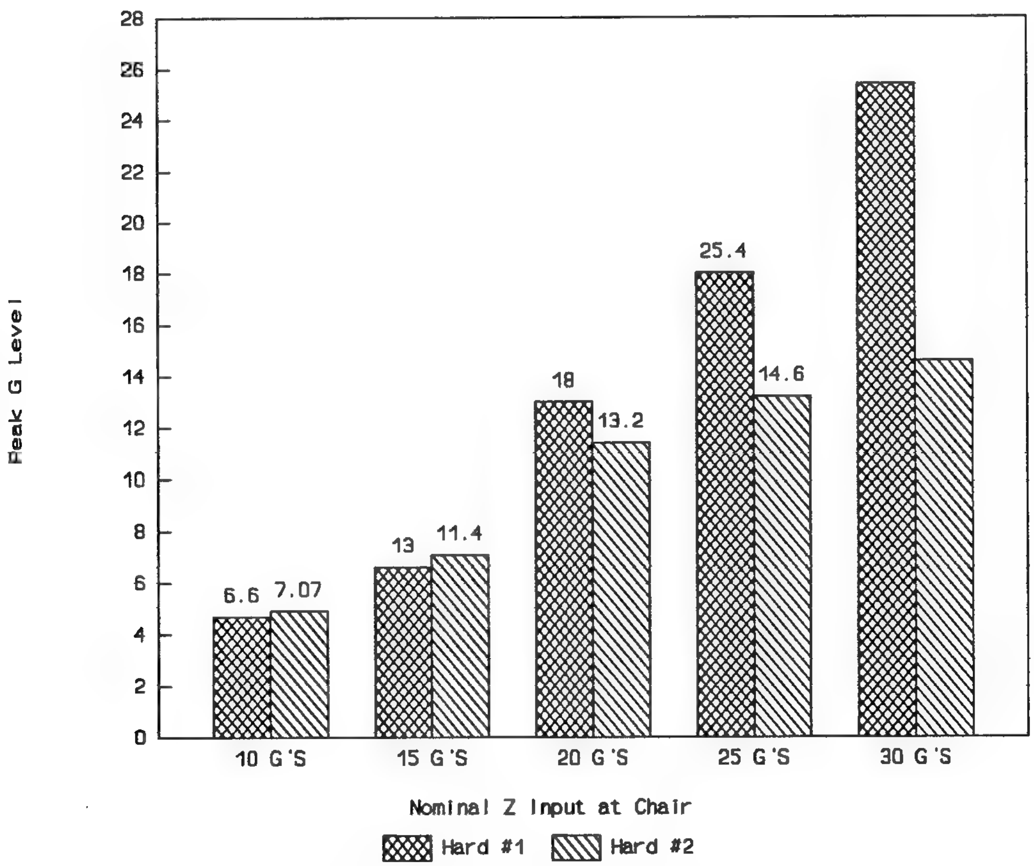


Figure 10. Hard Seat Pelvis X Comparison.

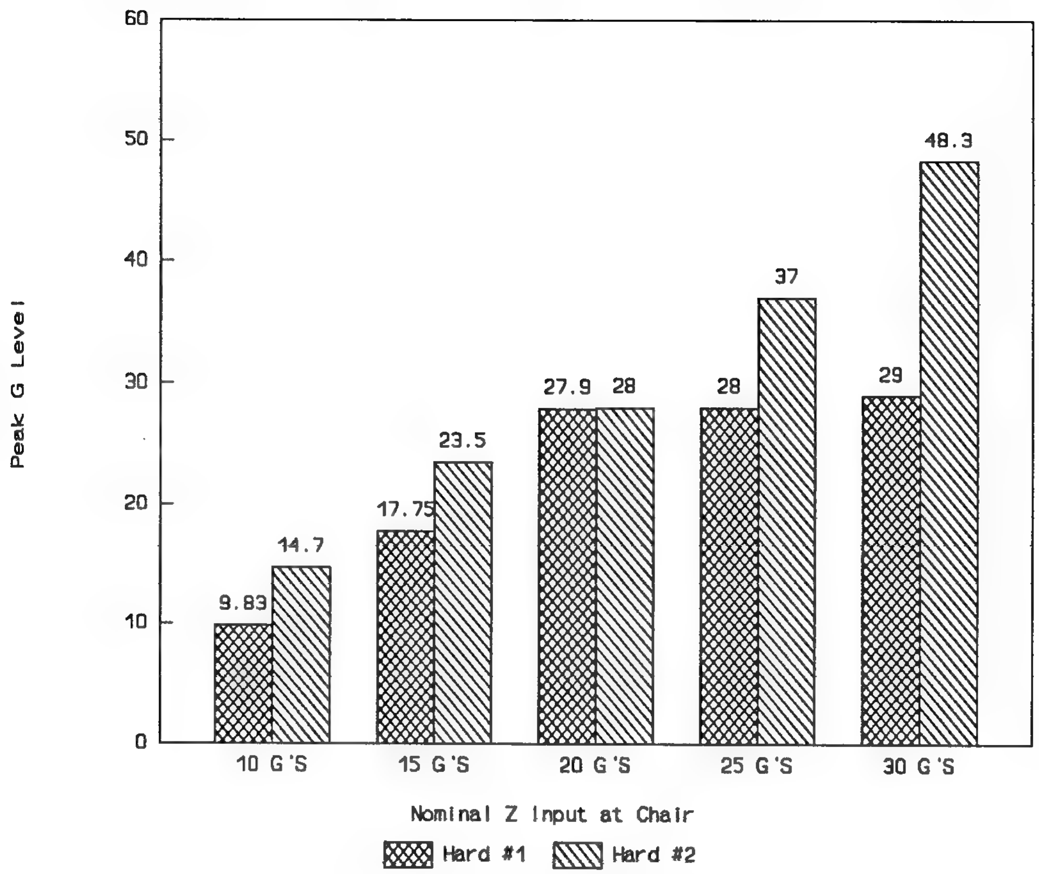


Figure 11. Hard Seat Pelvis Z Comparison.

3.3 MANIKIN RESPONSE

The primary dynamic response components of the manikin to +Z shock pulses are linear accelerations along the Z-axis at all three measurement stations, head rotation about the Y-axis, and head translation along the X-axis. Figures 12 and 13 are sample time history plots of shock propagation through the dummy's pelvis and T-1 for a nominal 25 G test utilizing the SPOC, and the hard seat respectively. The head responses as a function of time are shown in the Appendix. Figures 14 and 15 summarize the hard vs soft seat Z-axis peak acceleration propagation for two input levels of nominally 10 and 25 Gs. Figures 16 and 17 summarize head X-axis translation as well as head rotation about the Y-axis for two test replications at 10 and 25 Gs respectively.

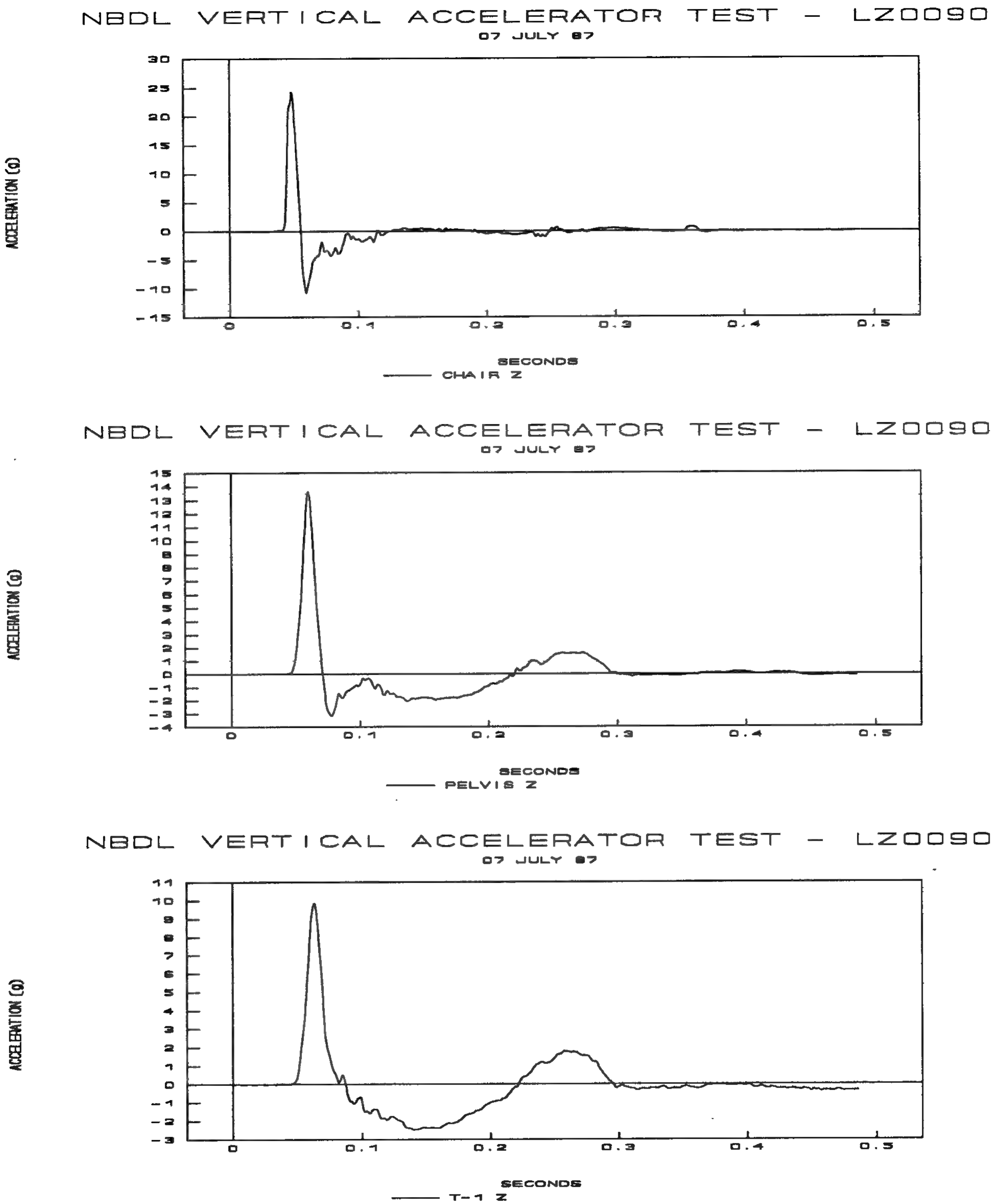


Figure 12. Shock Propagation through Pelvis and T-1 SPOC.

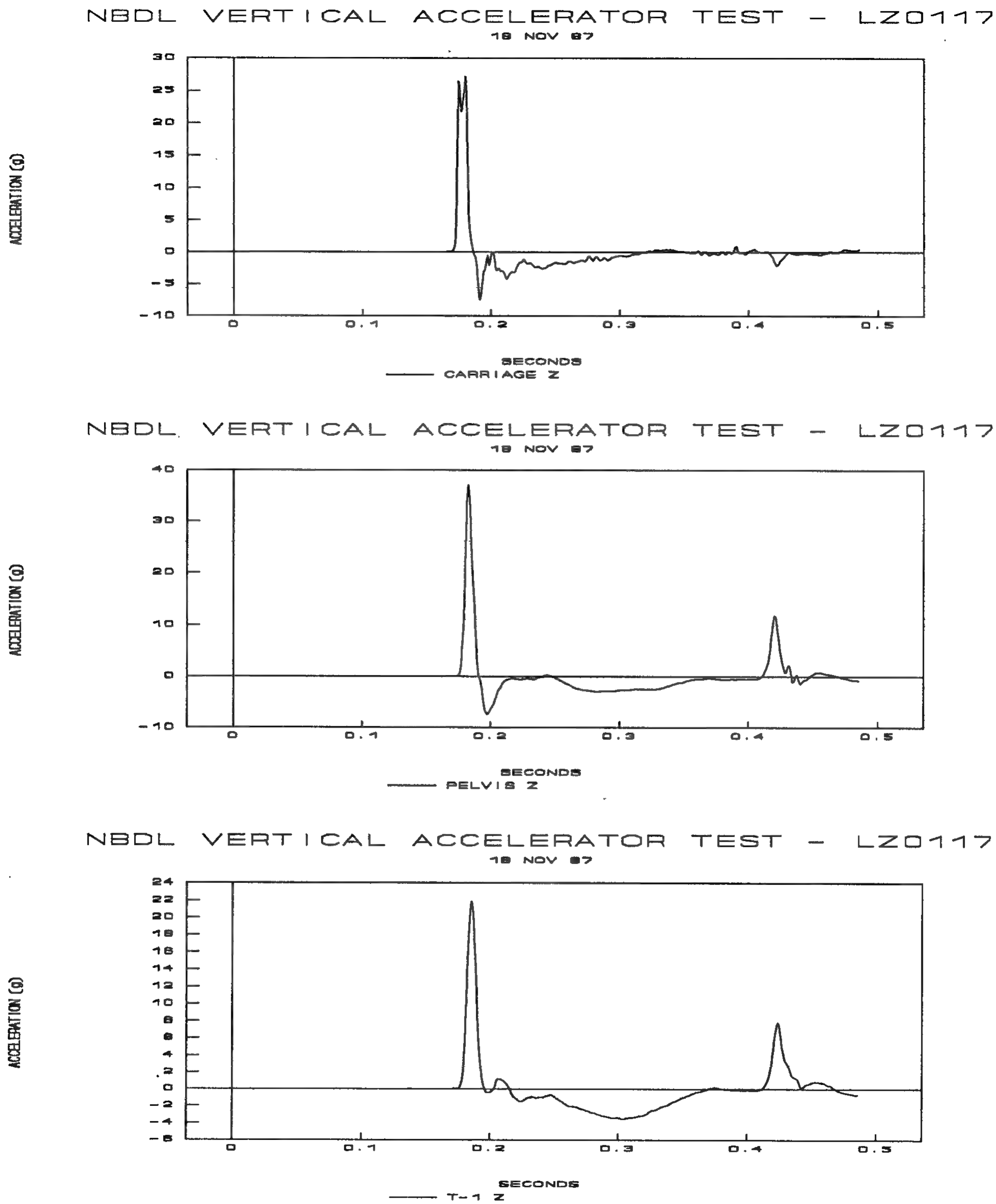


Figure 13. Shock Propagation through Pelvis and T-1 Hard Seat.

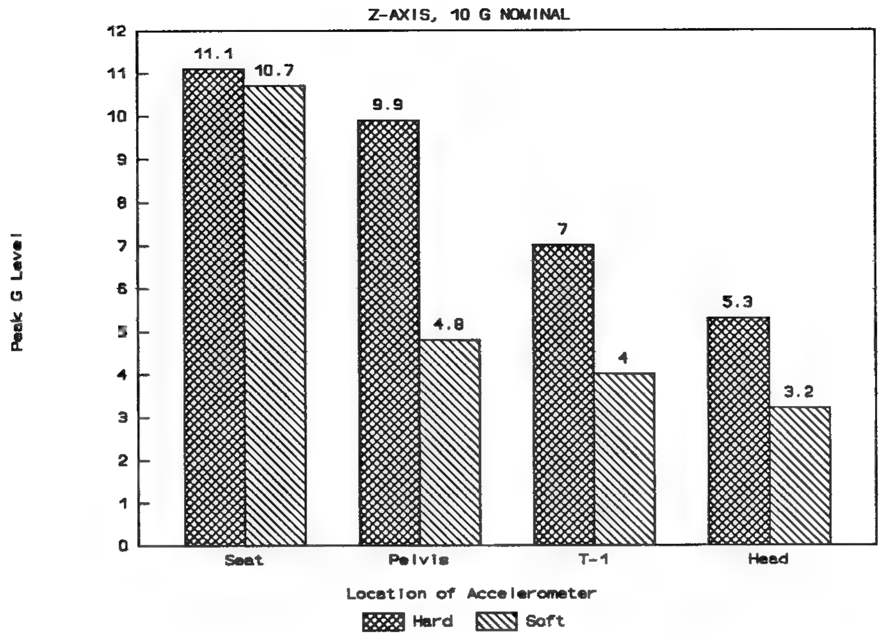


Figure 14. Hard vs. Soft Seat Comparison.

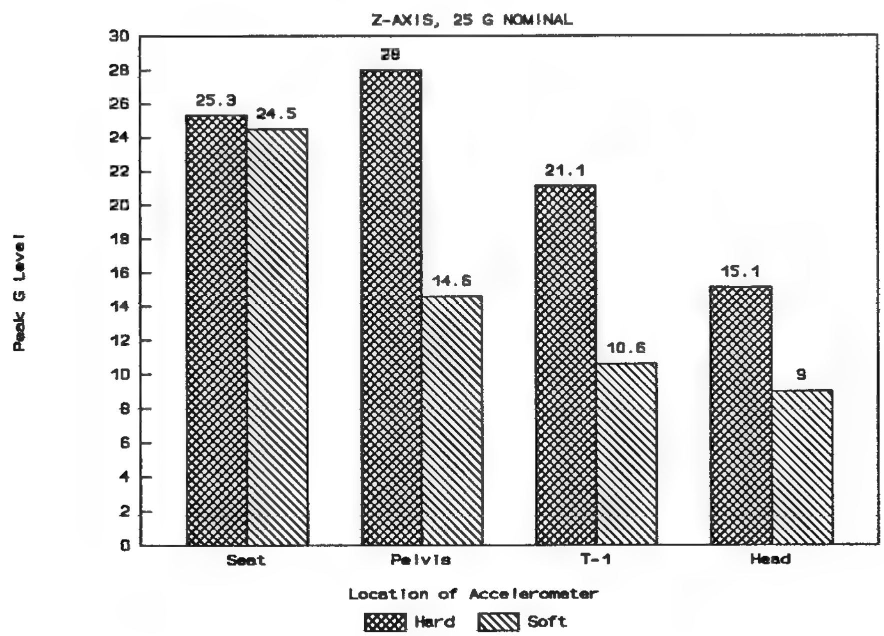


Figure 15. Hard vs. Soft Seat Comparison.

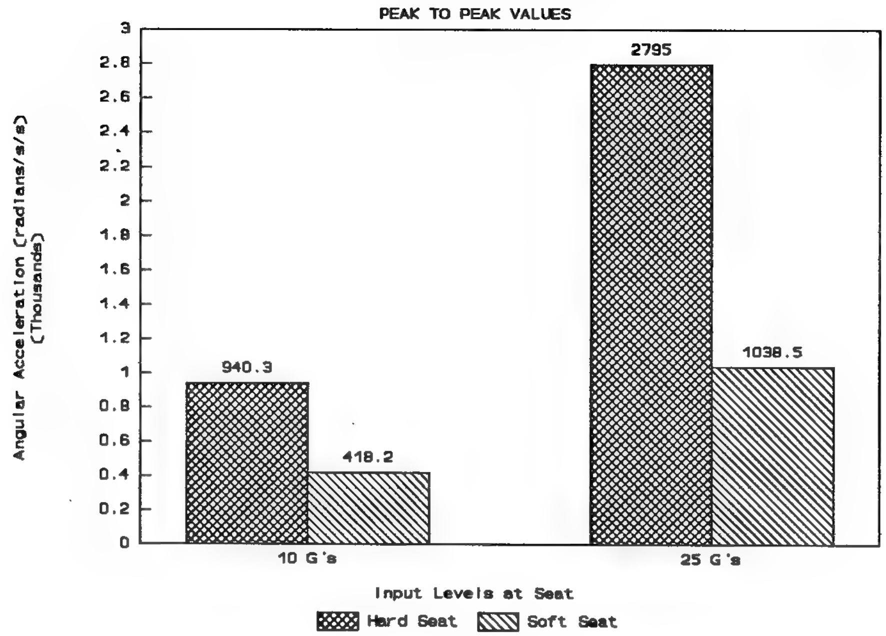


Figure 16. Head @Y Angular Acceleration.

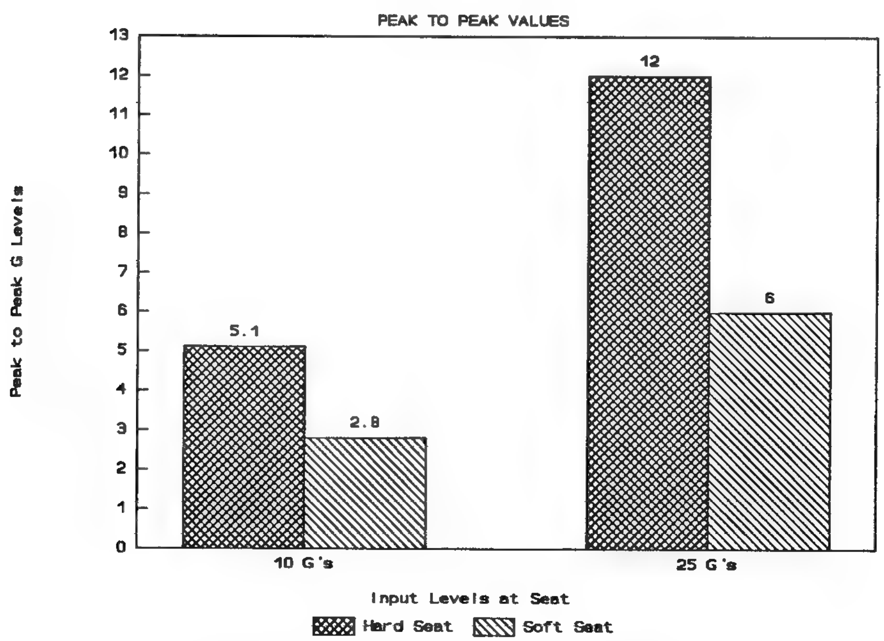
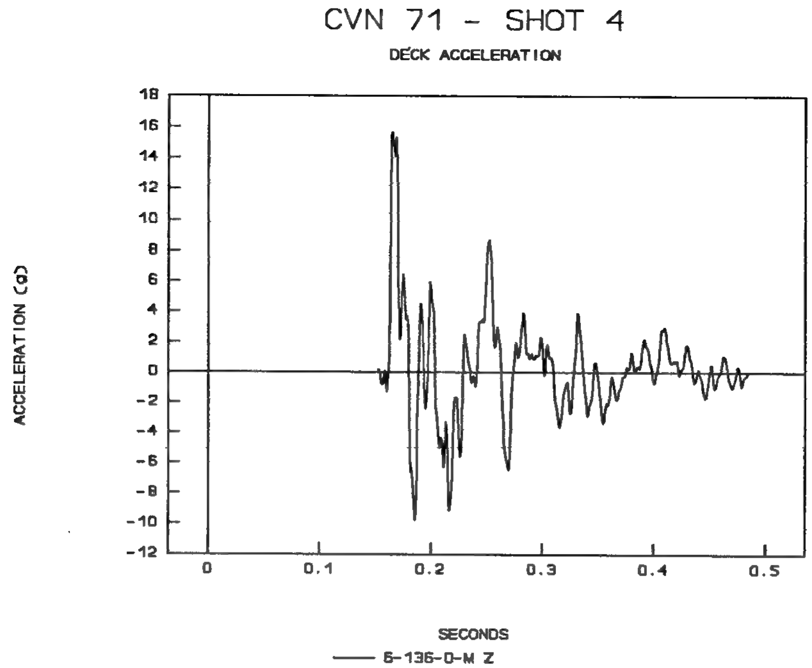


Figure 17. Head X Linear Acceleration.

In comparing the hard vs soft seat responses of the manikin, two things are evident. First the hard seat pelvic response of the manikin to the higher level inputs exhibit what appears to be a dynamic overshoot, i.e., the pelvis peak Z acceleration exceeds the input acceleration. Secondly, the soft seat does provide considerable shock attenuation. The dynamic overshoot phenomenon begins to manifest itself at approximately 15 Gs. The relative attenuation into T-1 and the head appear to be independent of the input acceleration level and the almost two-to-one attenuation afforded by the soft seat also seems to be independent of the input level.

A direct comparison of manikin response to simulated (Vertical Accelerator) and real (CVN-71 Shock Trials) shock inputs was made. These sample time traces are shown in Figures 18 through 21. Figure 18 depicts the input shock pulses; the relatively "noisy" response of the deck accelerometer, as compared to the USS YORKTOWN (CG-48) response (Figure 1), was probably due to its location within the ship. In the CVN-71 trials, the accelerometer was mounted on the deck in the middle of an empty ammunition magazine. As shown in the subsequent plots however, the manikin responds only to the primary pulse. It is evident from Figures 18 through 21 that the manikin's response to simulated shock is quite realistic even though in this shock trial the manikin was standing. Due to ocean bottom characteristics and because the CG-53 responded in an entirely different manner than the CG-48, data from the other trial which featured a seated dummy were not used. The simulated shock pulse more nearly replicated the CVN-71's response.



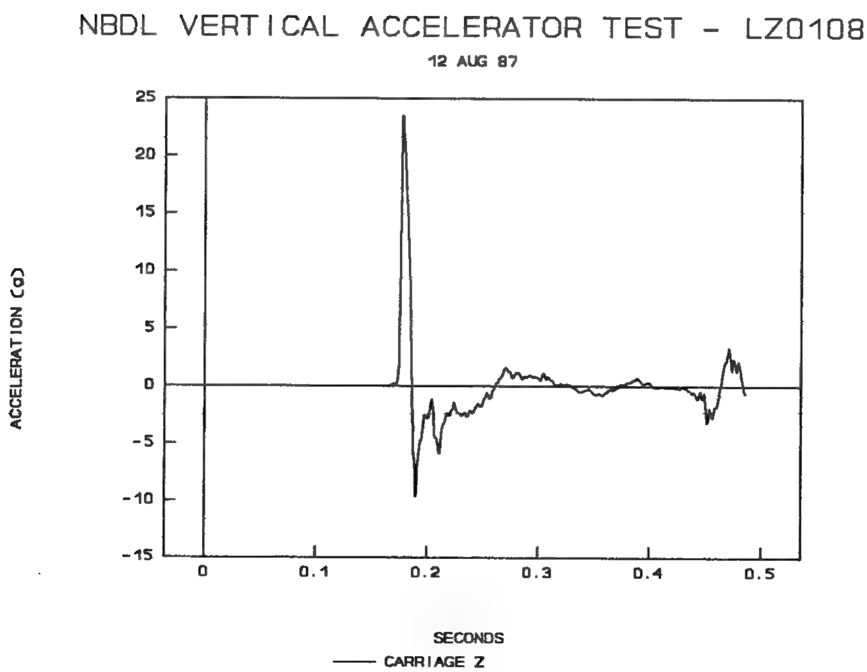


Figure 18. Comparison of Actual and Simulated Shock Pulses.

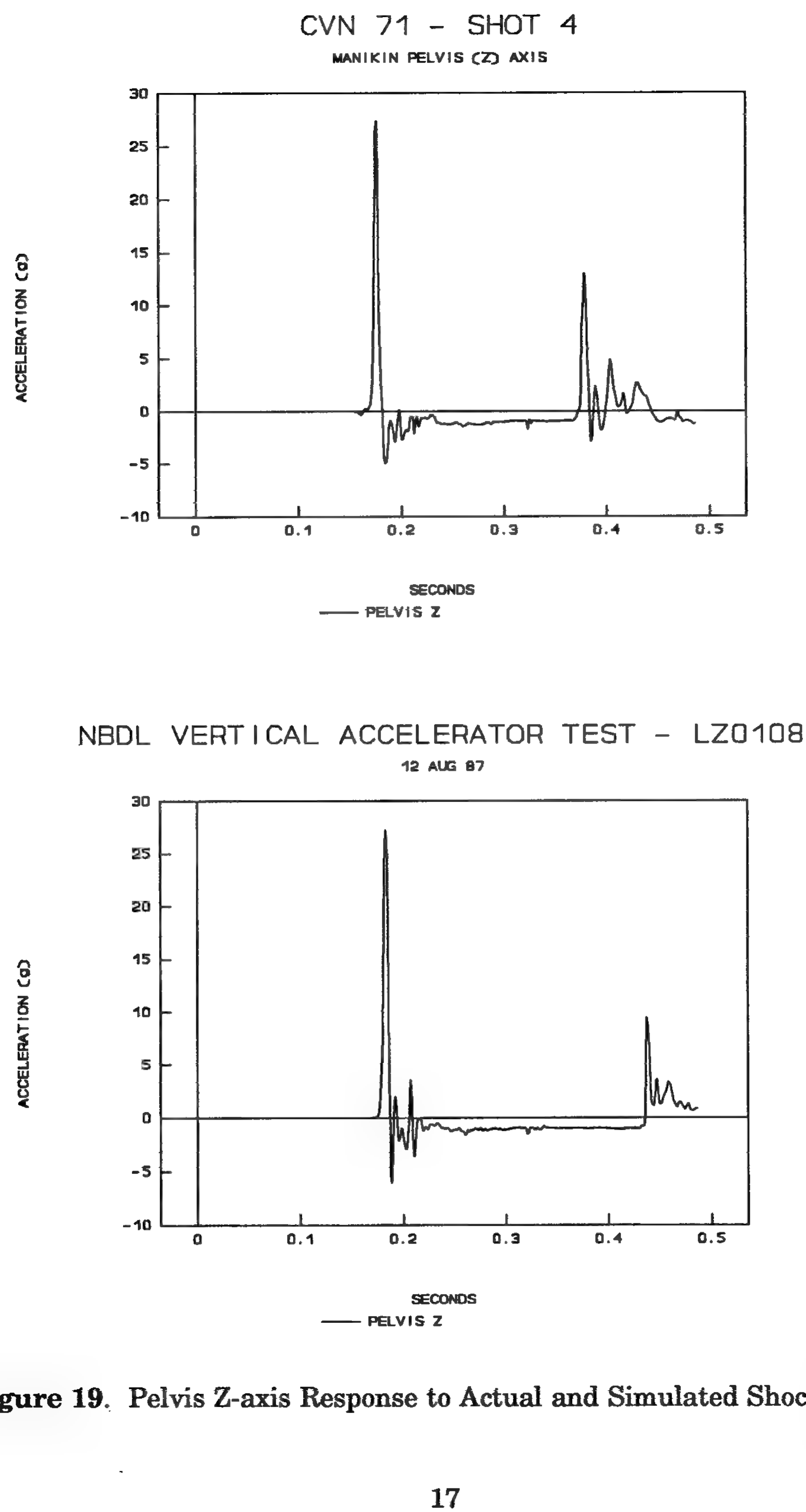


Figure 19. Pelvis Z-axis Response to Actual and Simulated Shock Pulses.

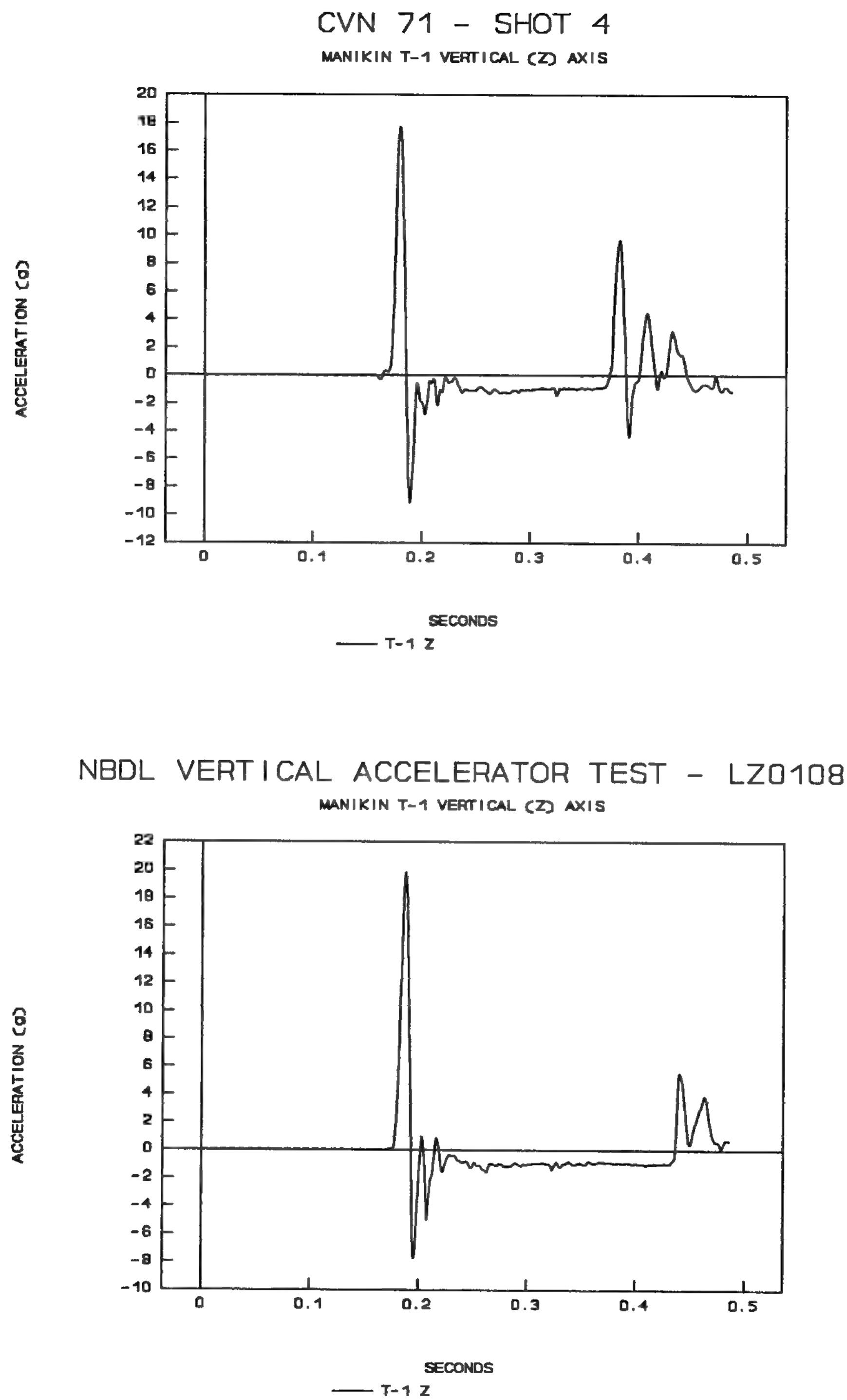
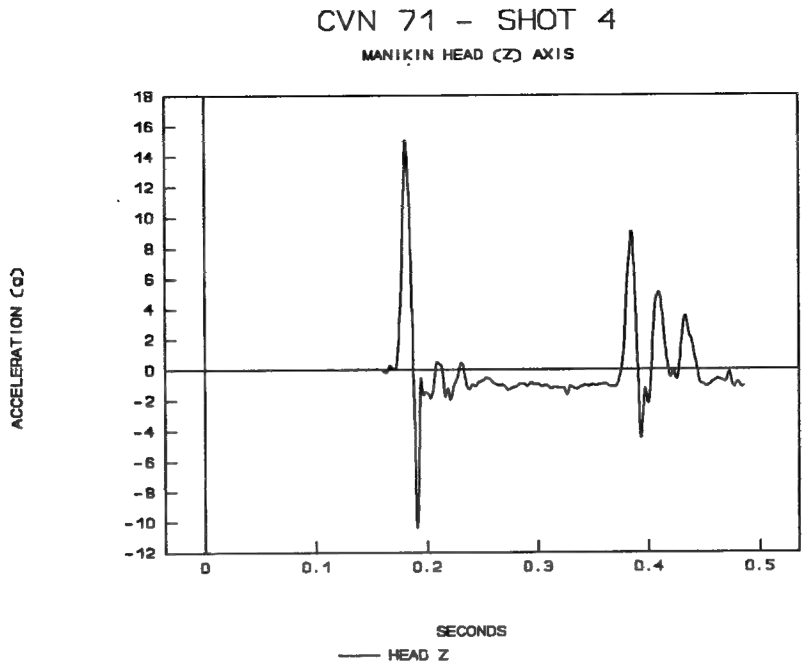


Figure 20. T-1 Z-axis Response to Actual and Simulated Shock Pulses.



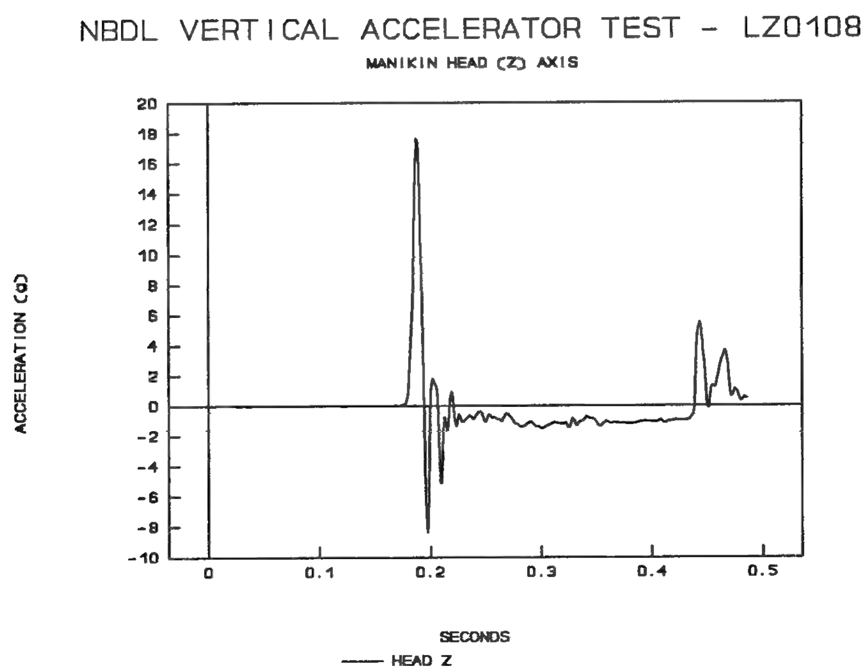


Figure 21. Head Z-axis Response to Actual and Simulated Shock Pulses.

4. SUMMARY

The principal component of impact acceleration during ship shock trials is along the Z-axis. NAVBIODYNLAB's Vertical Accelerator is able to accurately duplicate this shock pulse and can therefore, be used to realistically simulate ship response to underwater explosions. This capability has a number of potential applications.

The instrumentation developed to measure the dynamic response of various body anatomical segments and shock propagation through the body provides reliable and repeatable measurements of the motion.

Seat design can significantly attenuate the shock input into the body. The results presented herein for the SPOC can be generalized to other areas, resulting in a safer environment for ship crews. The shape of the hard surfaces in contact with the body can also materially affect the latter's response to shock.

5. CONCLUDING REMARKS

At the time the tests described herein were conducted, NAVBIODYNLAB's Vertical Accelerator was not man-rated. It was man-rated in 1989 and has since been used for a large number of experiments using human research volunteers. These test subjects are fully instrumented with inertial transducers similar to the ones described herein. Additionally, their motion is tracked in three dimensions with high speed cinematography. This capability could be exploited for performing studies in human response to ship shock at sub-injury levels. The result of these experiments would then yield both safe exposure limits for ship shock, and a database for the development of mathematical models of the response which would allow extrapolation to determine injury thresholds. The cost of such a study would be minuscule compared to the cost of performing a similar study during actual shock trials at sea.

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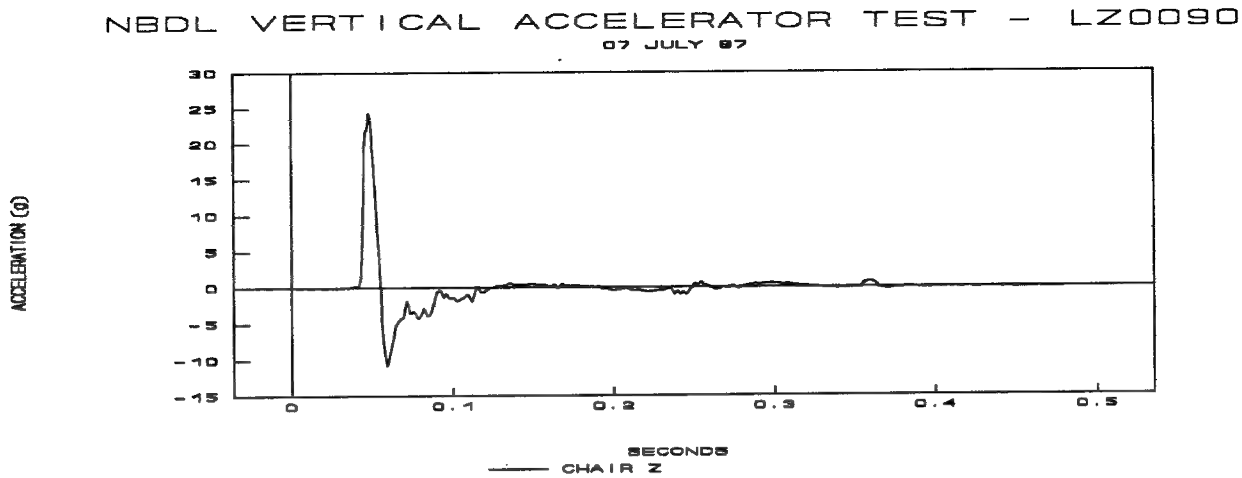
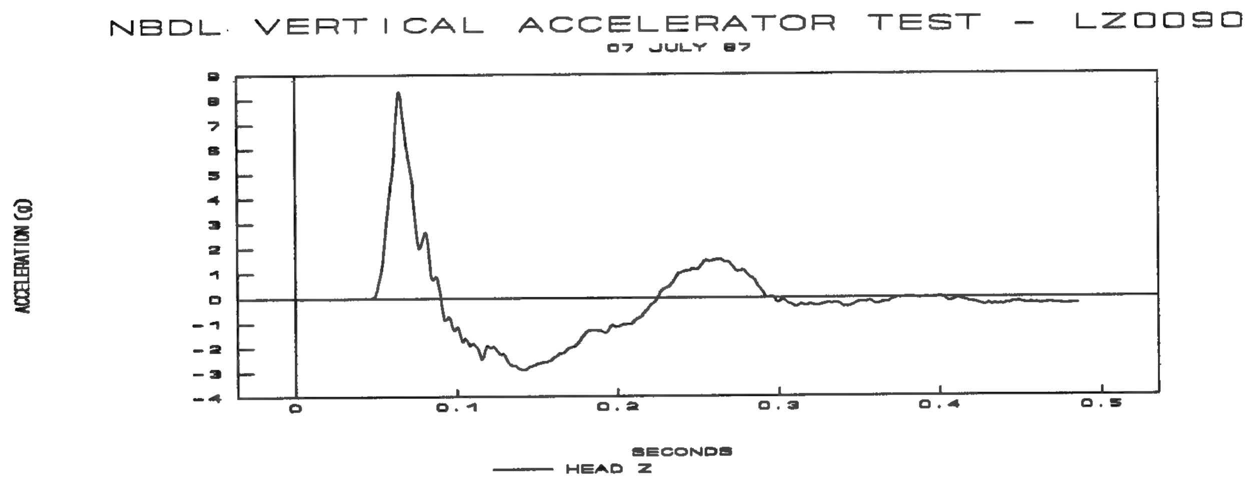
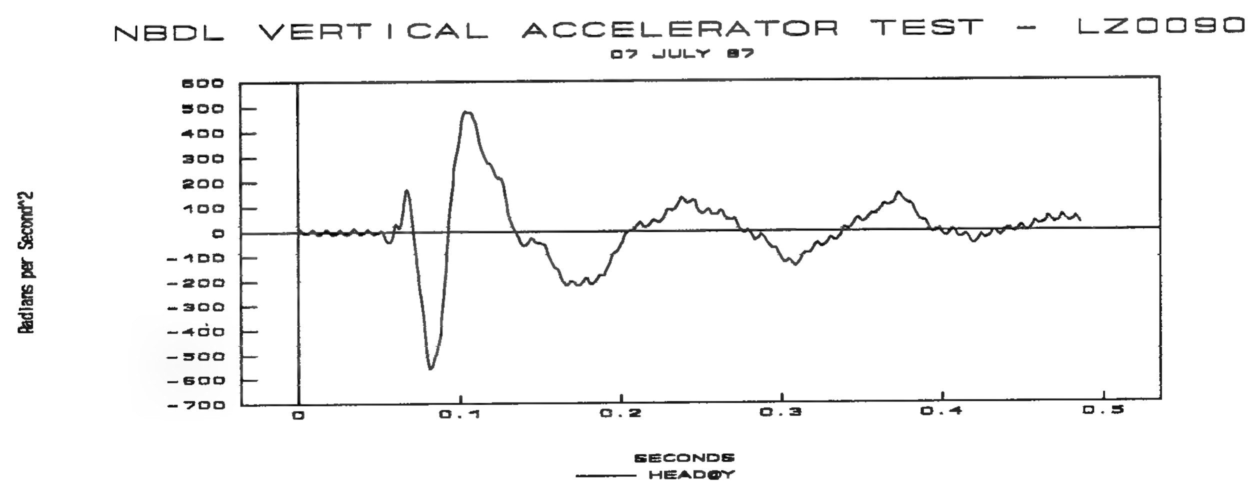
APPENDIX A

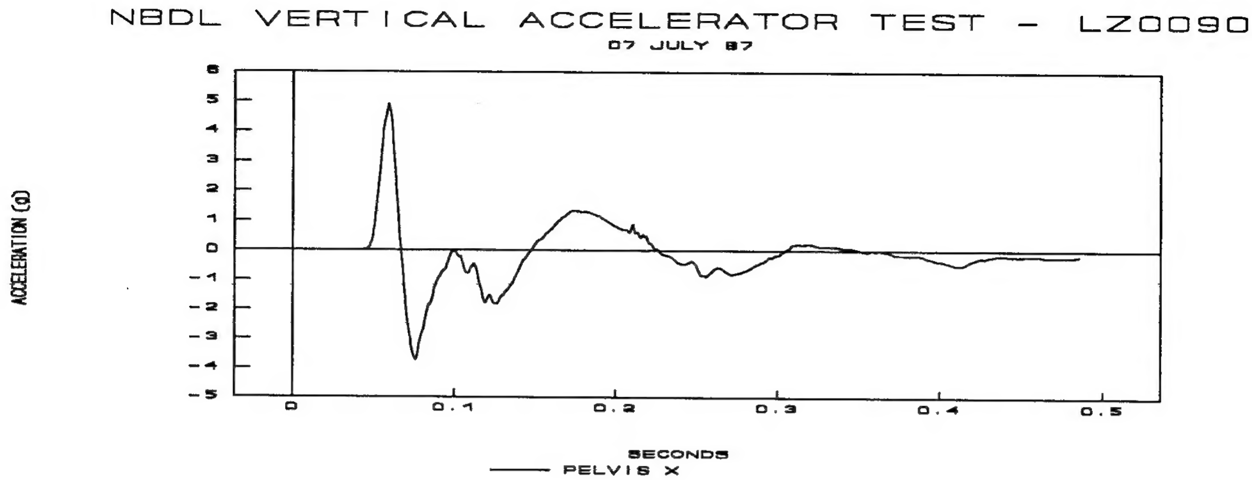
MANIKIN'S HEAD RESPONSES TO SIMULATED SHIP SHOCK AS A FUNCTION OF TIME

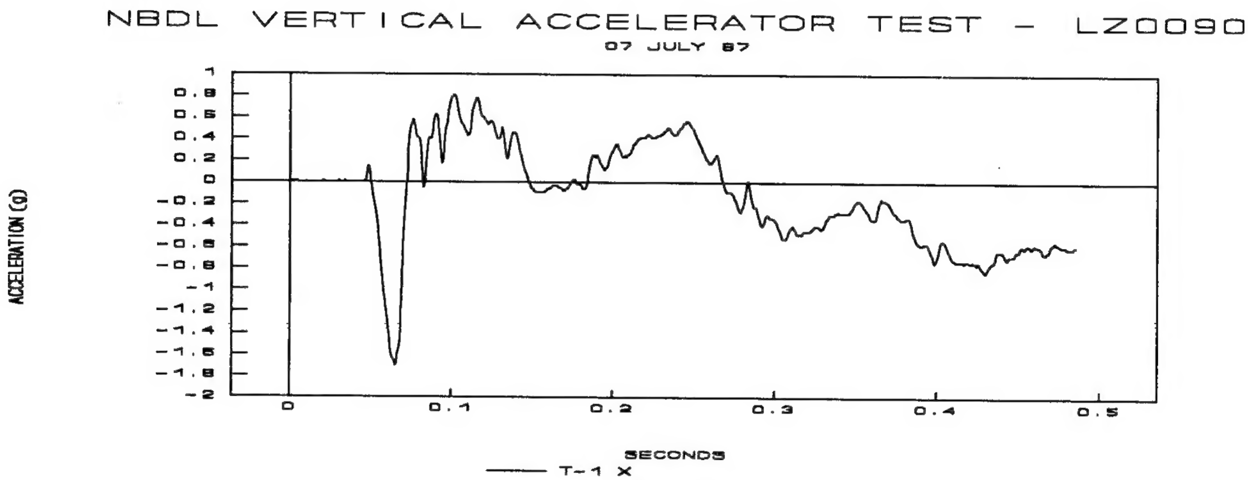


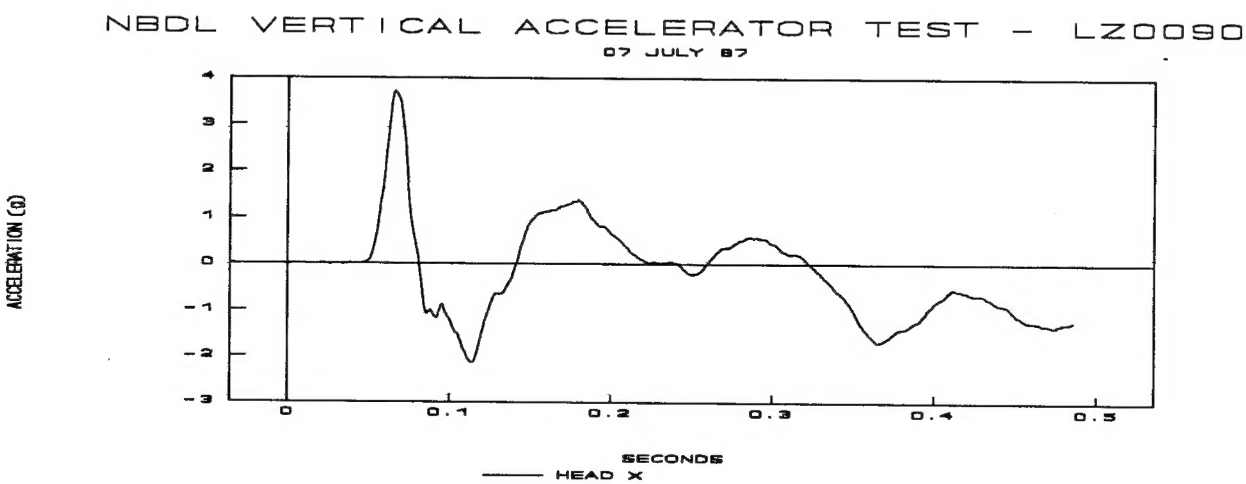




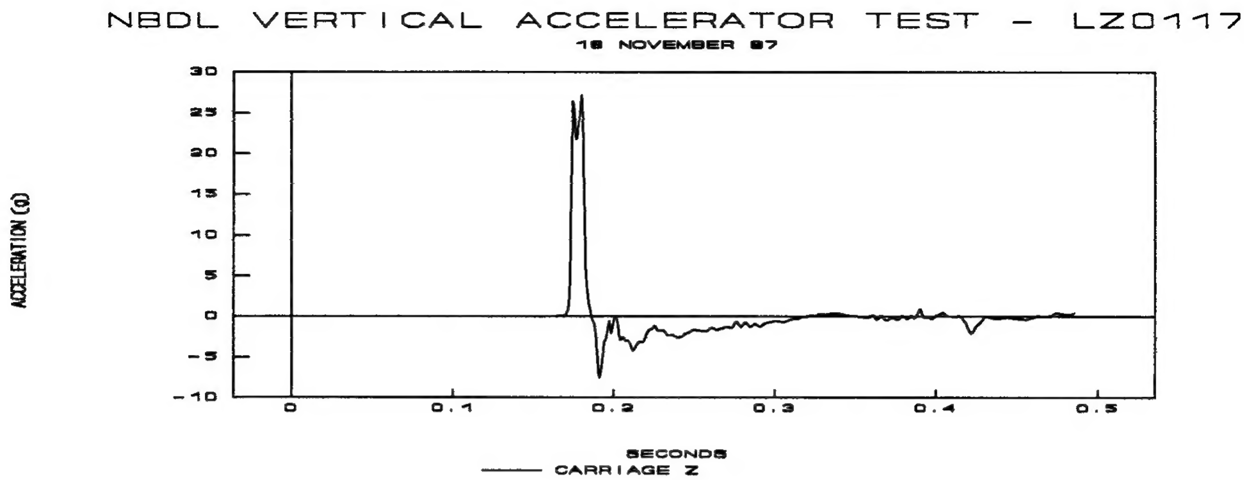
Head Linear and Angular Response to Shock - SPOC.

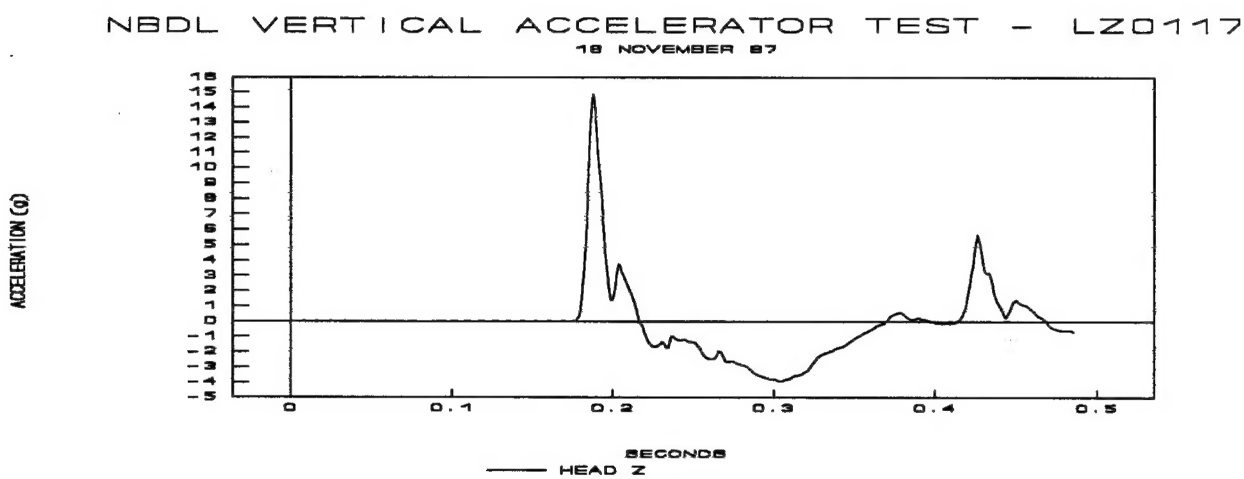


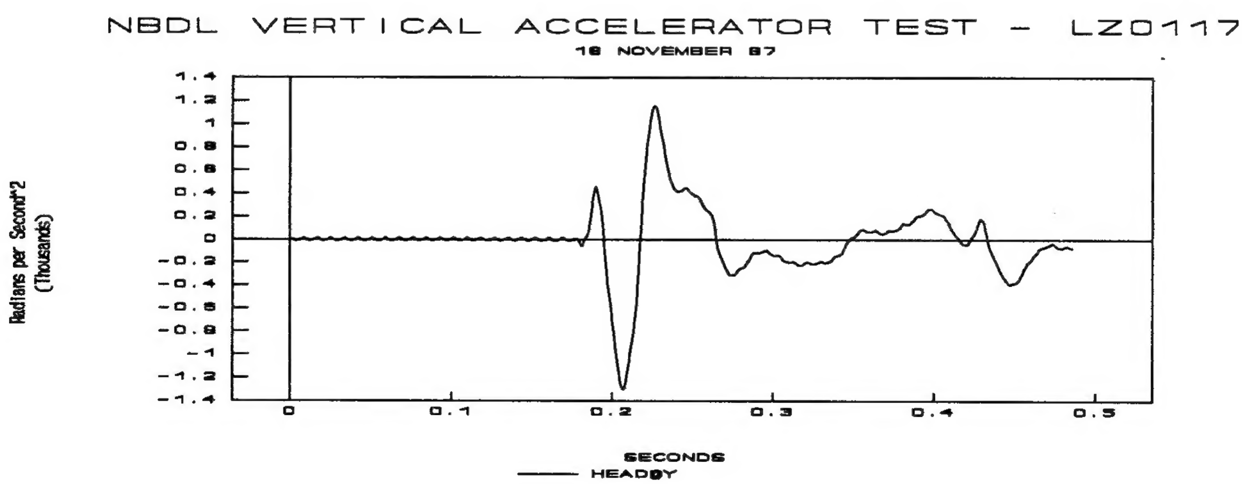




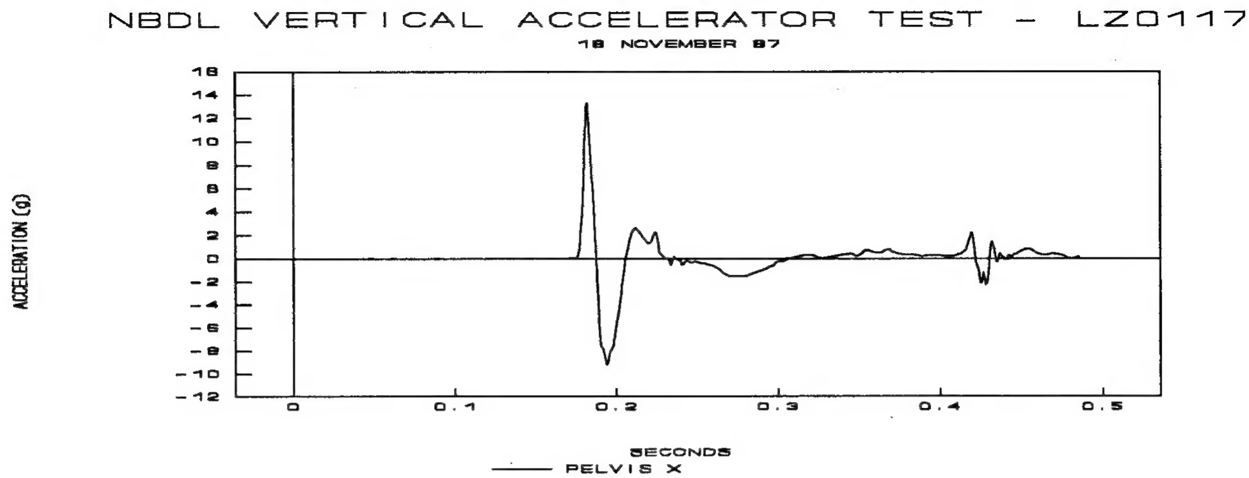
Dummy X-axis Response to Shock - SPOC.

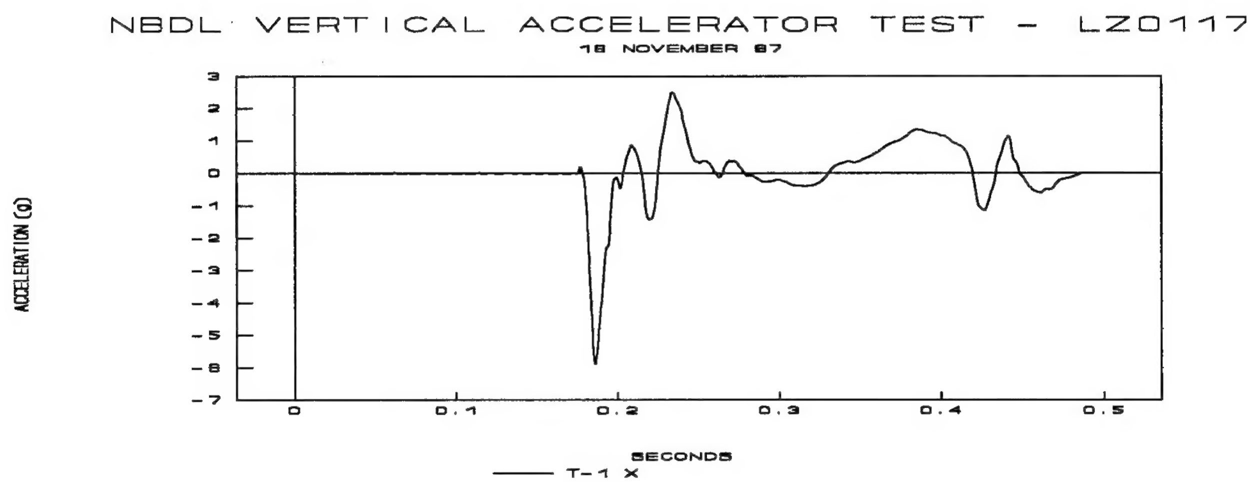


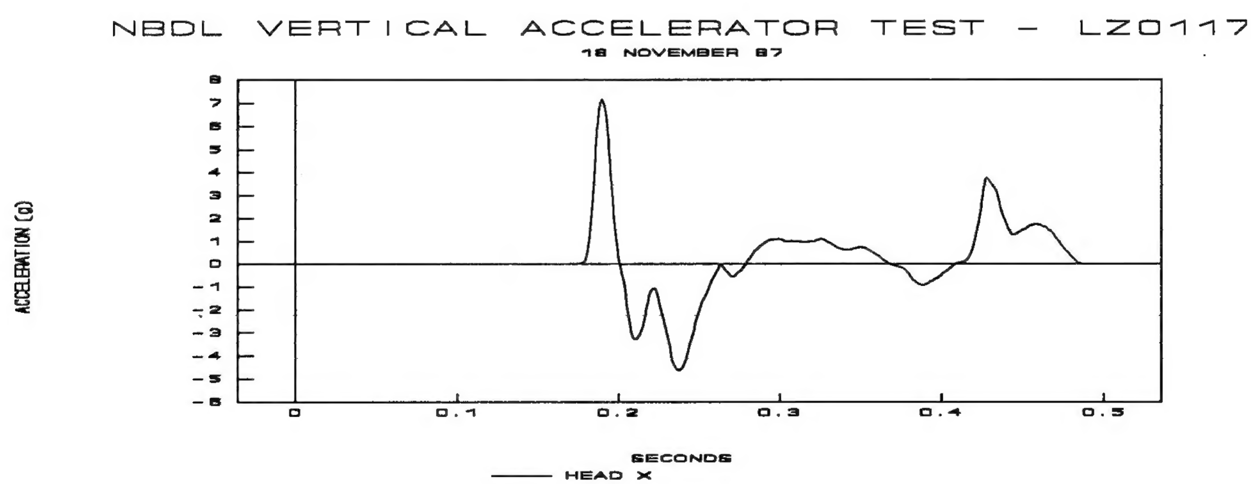




Head Linear and Angular Response to Shock - Hard Seat.







Dummy X-axis Response to Shock - Hard Seat.

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13. ABSTRACT *(Maximum 200 words)*
The response of an operator to simulated ship shock was evaluated for a subject seated on the Special Purpose Operator's Chair (SPOC). An instrumented Hybrid III manikin was vertically impacted at levels from 3 to 30 Gs on the Naval Biodynamics Laboratory's (NAVBIODYNLAB) Vertical Accelerator, adjusted to simulate ship Z-axis response to underwater explosions; the 30 G level exceeds the maximum values observed in several ship shock trials. The experiments were conducted using both the SPOC and two versions of a hard-bottomed seat in order to evaluate the shock attenuating capability of the SPOC. The evaluation of the capability of the Vertical Accelerator to accurately simulate ship shock and to produce repeatable results was also a goal of this program and was successfully achieved.

14. SUBJECT TERMS
Evaluate capability of Vertical Accelerator; stimulate ship shock; produce repeatable results.

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